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(71) Applicant: Komatsu, Ltd.
Tokyo-to, Minato-ku, Akasaka Ni-chome, 3-ban, 6-go

(72) Inventor: Satoshi Wakabayashi
c/o Research Institute of Komatsu, Ltd.
Shinagawa-ken, Hiratsuka-shi, Banda 1200

(72) Inventor: Senso Ito
c/o Research Institute of Komatsu, Ltd.
Shinagawa-ken, Hiratsuka-shi, Banda 1200

(72) Inventor: Kei Mizoguchi
c/o Research Institute of Komatsu, Ltd.
Shinagawa-ken, Hiratsuka-shi, Banda 1200

(74) Representative: Takahisa Kimura, patent attorney

(54) Title of the Invention: Pulse Energy Control Device of a Pulse Laser Device And Its Method

(57) Summary

(Purpose)

The purpose of this invention is to realize a pulse energy control device making it possible to exercise control per 1 pulse over pulse energy with optimal precision at high speeds.

(Construction)

The pulse energy value required from an exposure device (3) for next operations is input to a pulse energy controller (5), the pulse energy controller (5) controls attenuator (2) with instructions containing the energy value and a specified pulse energy is input to exposure device (3).

[diagram]

2 attenuator
3 optical device
4 driver
5 pulse energy controller
11 narrow band unit
12 laser tube
14 detector
15 laser controller <- laser pulse

[page 2]

(Scope of the Patent's Claims)

(Claim 1)

A pulse energy control device of a pulse laser device controlling the output of energy of a pulse laser device,

characterized by the fact that it comprises a pulse energy setting means which sets the value of required pulse energy per each pulse;

a variable light attenuation means decreasing the light energy of output light by varying the transmittance of the output light, deployed on the output side of said pulse laser device;

a pulse energy forecasting means which calculates the forecast value of output pulse energy of said pulse laser device;

a transmittance calculating means which calculates transmittance with said variable light attenuation means from the forecast value of the output pulse energy calculated with said pulse energy forecast means and from a value set by said pulse energy setting means;

and a transmittance controlling means which controls the transmittance of said variable attenuation means so as to achieve coincidence with the calculated value of said transmittance calculating means.

(Claim 2)

The pulse energy control device of a pulse laser device of claim 1, characterized by the fact that it is provided with a pulse energy forecast value calculating means which calculates the forecast value of the output pulse energy in the form of parameters including the laser gas status and charging voltage of the excitation condenser, as well as the excitation strength and the oscillation time period.

(Claim 3)

The pulse energy control device of a pulse laser device of claim 1, characterized by the fact that it is provided with a memory means which stores in memory the relationship between the pulse energy and said parameters from the previous cycle and prior to the previous cycle,

having a pulse energy forecast value calculating means which calculates the forecast energy of the output pulse energy from the content stored in said memory means.

(Claim 4)

The pulse energy control device of a pulse laser device of claim 1, characterized by the fact that during the burst mode of oscillation, including a specified oscillation pause time period, and a specified number of pulse sequences with a specified number of pulses,

the relationship of the pulse energy to the charging voltage of the excitation condenser or of the excitation strength is stored in memory with the previous burst mode or the mode prior to this one,

and the forecast value of the output pulse energy is calculated in accordance with this relationship.

(Claim 5)

A pulse energy control device of a pulse laser device, characterized by the fact that it is provided with a burst energy setting means which sets a pulse energy value required for each pulse,

a variable light attenuation means which decreases the energy of the output light by varying the transmittance of the output light, deployed on the output side of said pulse laser device,

and a pulse energy controlling means which controls the value of the pulse energy output by said pulse laser device to achieve coincidence between the calculated value of said transmittance calculating means and the transmittance of said variable light attenuation means.

(Claim 6)

The pulse energy control device of a pulse laser device of claim 1 or claim 5, characterized by the fact that it is equipped with a first and a second energy detecting means detecting laser pulse energy, mounted respectively on the input side and on the output side of said variable light attenuation means,

and with a transmittance correcting means which corrects the relationship between the transmittance of said variable light attenuation means and the control value of said transmittance control value, based on the values detected with said first and second energy detecting means.

(Claim7)

The pulse energy control device of a pulse laser device of claim 1 or claim 5, characterized by the fact that variable light attenuation is conducted by changing the selection wavelength of a wavelength selection element.

(Claim 8)

The pulse energy control device of a pulse laser device of claim 7, characterized by the fact that an air gap etalon is used as said wavelength selection element and that it is equipped with a gap interval controlling means which controls the gap interval of said air gap etalon.

(Claim 9)

The pulse energy control device of a pulse laser device of claim 8, characterized by the fact that the configuration of said gap interval controlling means comprises a piezoelectric element.

(Claim 10)

The pulse energy control device of a pulse laser device of claim 7, characterized by the fact tnat said variable attenuation means uses an air gap etalon for said wavelength selection element,

wherein the reflectance of the mirror used in said air gap etalon is no more than 39%.

(Claim 11)

The pulse energy control device of a pulse laser device of claim 1 or claim 5, characterized by the fact that it comprises a standard light transmitting means which transmits standard light to said variable attenuation means,

a standard light transmission output detection means which detects the transmitted output of said standard light,

and a transmittance correcting means which corrects the relationship between said variable light attenuation means and the control value of said transmittance controlling means based on the values detected by said standard transmittance output detecting means.

(Claim 12)

The pulse energy control device of the pulse laser device of claim 1 or claim 5, characterized by the fact that said variable light attenuation means is equipped with a configuration combining a stress modulator with a light deflecting plate, as well as with an amplitude controlling means which controls the amplitude of the oscillations applied to said stress modulator.

[page 3]

(Claim 13)

A pulse energy control method of a pulse laser device, characterized by the fact that the pulse energy level required for each pulse is set with a pulse energy controlling method which controls the output energy of a pulse laser device,

the pulse energy is decreased by varying the transmittance of the output light on the output side of said pulse laser device,

the forecast value of the pulse energy output by said pulse laser device is calculated,

and the transmittance created by said attenuation is calculated from said forecast value of said output pulse energy calculated with a set value which is set for said pulse energy,

enabling to exercise control so as to match said calculated transmittance with the real transmittance.

(Claim 14)

A pulse energy control method of a pulse laser device, characterized by the fact that the pulse energy level required for each pulse is set with a pulse energy controlling method which controls the output energy of a pulse laser device,

the pulse energy is decreased by varying the transmittance of the light output on the output light side of said pulse laser device,

the pulse energy output by said pulse laser device is controlled at a specified value,

and the transmittance generated with said attenuation is calculated from said controlled output pulse energy value and from a set value set for said pule energy,

enabling to exercise control so as to match said calculated transmittance with the real transmittance.

(Detailed Explanation of the Invention)

This invention relates to an improved pulse energy control device of a pulse laser device used as a light source of a processing apparatus or an exposing apparatus for semiconductors.

(0002)

(Prior Art Technology)

It is known that the output light of pulse laser devices is a pulse light and that the energy of reciprocal pulses in this light will be characterized by fluctuations. In order to control the light exposure value in the output of a pulse laser device with predetermined fluctuations of this energy according to prior art technology, as many pulse as possible were applied to the output light of a pulse laser per 1 exposure so as to reduce the total fluctuations of the light exposure value.

(0003)

On the other hand, the exposure had to be realized with a small number of pulses in order to increase the throughput of the exposure device.

(0004)

Japanese Unexamined (Kokai) Application Number Hei 2-5063 discloses a method invented to realize exposure control enabling a high precision with a small number of pulses. According to this invention, a variable attenuator 92 is deployed in order to forcibly attenuate light pulses between exposure device 94 and laser light source 91 creating a pulse system. In addition, to detect the influence of this variable attenuator 92, the light exposure value amount is measured in one part of the light pulse with a light exposure value monitor 93, and a control part 95 which is connected to this variable attenuator 92 and light source 91 is used to control the minimum determined attenuation amount required to realize a desirable exposure based on the value measured with exposure value monitor 93. (Figure 25).

(0005)

On the other hand, because when a pulse laser device such as an excimer laser is used, a repeating burst mode is controlled with pauses applied in constant intervals after the pulse oscillations have been conducted with a specified number of pulses as shown in Figure 26, this will greatly increase the fluctuations of the energy due to a so called spiking phenomenon which greatly increases the pulse energy of initial fluctuations.

(0006)

The inventors of this invention have already described in Japanese Unexamined Patent Application Number Hei 6-169123 a method enabling to reduce the spiking phenomenon by varying the charging voltage applied to the excitation condenser or by varying the excitation strength of the parameters during the oscillation pause period in order to eliminate this spiking phenomenon of the initial burst in this case.

(0007)

However, the exposure techniques used with semiconductor exposure devices in recent years have been characterized by a transition from the stepper method to the scanner method (see NIKKEI MICRODEVICES, September 1993 Issue, page 54 ~ 59.

(0008)

The scanner method is an exposure method according to which exposure is achieved while beams are emitted from a scanner. According to this method, however, it is not possible to control the light exposure value with a high precision in a specified location with a conventional irradiation method achieving a specified cumulative value of the light pulse energy representing specified light pulses in the same location of a processed object. The scanner method is a method enabling to measure the light exposure value at the beginning of each pulse creating pulse energy. Accordingly, the exposure must be conducted at a high speed during processing while the high-speed pulse energy is controlled based on the calculated values.

(0009)

Another problem is that when the required pulse energy is calculated based on the processing status during processing conducted with the pulse laser light, the processing depth must be also controlled with a high precision when a pulse energy generated at a high speed is controlled on the basis of calculated values.

(0010)

(Problems To Be Solved By This Invention)

In view of the above described facts, it was difficult to control with a high precision the value of the light exposure in each of the locations scanned by beams since the required energy had to be realized with a small number of pulses to make it possible to apply control in order to reduce the fluctuations of the total cumulative energy amount when the pulse energy was calculated with a conventional light pulse energy controlling method. The purpose of this invention is to resolve this problem by providing a pulse energy control device and a method to control such a device enabling to conduct light exposure and processing with a high precision by controlling a pulse energy value set per each pulse.

(0011)

(Means To Solve Problems)

In order to achieve this purpose, this invention provides a pulse energy control device of a pulse laser device controlling the output energy of a pulse laser device,

[page 4]

characterized by the fact that it is equipped with a pulse energy setting means which sets the value of the pulse energy required per each pulse;

a variable optical attenuator means for the output light enabling to vary the optical transmittance of the output light, mounted on the output side of said pulse laser device;

a pulse energy forecasting means which calculates the forecasted value of the output pulse energy of said pulse laser device;

a transmittance calculating means which calculates the transmittance of said variable attenuation means based on the forecasted value of the output pulse energy calculated by said pulse energy forecasting means and based on the value set by said pulse energy setting means;

and with a transmittance controlling means which applies control to match the calculated

value of said transmittance calculating means with the transmittance of said variable attenuator means.

(0012)

Said pulse energy forecasting means is further characterized by the fact that it is provided with a pulse energy forecast value calculating means which calculates the forecast value of the output pulse energy as a parameter of the laser gas state and of the charging voltage of the excitation condenser, or of the excitation strength and time period of a pause in oscillations.

(0013)

Further, said pulse energy forecast value calculating means is also provided with a parameter memory means which stores in memory the parameters of the previous cycle and the parameters before the previous cycle in order to estimate the tendency of the variations of said parameters based on the content of the parameters stored in memory of said parameter storage means; including a pulse energy forecast value estimating means which calculates the forecast value of the output pulse energy based on this estimated tendency.

(0014)

Furthermore, said pulse energy forecast value calculating means stores in memory the relationship between the pulse energy and the charging voltage of the excitation condenser or of the excitation strength during the previous cycle or during the previous burst mode when a burst mode is generated with oscillations characterized by a specified pause in oscillations, as well as a specified number of pulse sequences during a specified number of pulses.

(0015)

The pulse energy control device of the pulse device controlling the output energy of a pulse laser device is also equipped with a pulse energy setting means which sets the value of pulse energy required for each pulse, a variable light attenuation means which decreases the energy of the output light by varying the transmittance of the output light, mounted on the output side of said pulse laser device; with a pulse energy controlling means which control the value set for the output pulse energy of said pulse laser device; a transmittance calculating means which calculates transmittance with said variable light attenuation means based on the output pulse energy value controlled by said pulse energy controlling means and based on the value set by said pulse energy setting means; and with a transmittance controlling means which applies control in order to match the transmittance of said variable light attenuation means with the value calculated by said transmittance calculating means.

(0016)

The inventions is also characterized by the fact that it is equipped with a transmittance compensating means which applies compensation to the relationship between the transmittance of said variable light attenuation means and the control value of said transmittance controlling means based on the value detected by a first and second energy detection means, when a first and a second detection means used to detect laser pulse energy are mounted on the input side and on the output side of the light in said variable light attenuation means.

(0017)

Said variable light attenuation means is further characterized by the fact that it can update the selection wavelength of a wavelength selection element.

(0018)

Said variable light attenuation means is also characterized by the fact that it uses an air gap etalon as said wavelength selection element and that it is equipped with a gap interval controlling means which controls the gap interval of said air gap etalon.

(0019)

Said gap interval controlling means is further characterized by the fact that its is constructed with a piezoelectric element.

(0020)

Said variable attenuation means is characterized by the fact that it uses an air gap etalon in said wavelength selection element and that the reflectance of the mirror used in said air gap etalon is no more than 39%.

(0021)

Another characteristic of this invention is that it is equipped with a standard light transmitting means transmitting standard light to said variable light attenuation means, a standard light transmittance output detection means detecting the transmittance output of said standard light, and with a transmittance correcting means providing compensation for the relationship between the transmittance of said variable light attenuation means and the correction value of said transmittance correcting means based on the output value of said standard light transmittance output detection means.

(0022)

A further characteristic is that said variable light attenuation means is provided with a construction combining a deflecting plate with a stress modulator and that it is equipped also

with an amplitude controlling means which controls the amplitude of the oscillations applied to said stress modulator.

(0023)

According to yet another characteristic relating to the method used to control the pulse energy by applying control to the output energy of the pulse laser device, a required pulse energy value is set for each pulse and the pulse energy is attenuated by modifying the transmittance of the output light on the output side of said pulse laser device, a forecast value of the output pulse energy of said pulse laser device is calculated, and the transmittance created by said attenuation is calculated from the forecast value of said output pulse energy by calculating the value set for said pulse energy in order to match the real transmittance with the calculated transmittance.

(0024)

According to yet another characteristic relating to the method used to control the pulse energy by applying control to the output energy of the pulse laser device, the pulse energy is attenuated by varying the transmittance of the output light on the output side of said pulse laser device, the output pulse energy of said pulse laser device is controlled to maintain a set value, the transmittance created by said attenuation is calculated based on said output pulse energy value controlled by the value set for said pulse energy, and the transmittance created by said attenuation is calculated from the forecast value of said output pulse energy by calculating the value set for said pulse energy in order to match the real transmittance with the calculated transmittance.

(0025)

(Operation)

According to this invention, forecast calculations are run to calculate the next pulse energy which will be output from the laser, enabling to control the transmittance of the variable light attenuation means for each pulse so as to achieve a pulse energy which is set for the output pulse energy level. In addition, the variable light attenuation means can be controlled per each pulse so as to achieve a set pulse energy value for each pulse energy level and to create a specific pulse energy with the cumulative value of the laser pulses. This enables an optimal control which can be applied to the pulse energy at a high speed and with a high precision

[page 5]

Accordingly, this makes it possible to realize an optimal device in the form of a pulse energy controlling device which can be used for processing requiring a highly precise control of the depth of processing in an optical exposure device using the scan exposure method.

(0026)

(Embodiments)

The following is a detailed explanation of a pulse laser control device of a pulse laser of this invention and its control method based on the reference provided in the enclosed figures.

(0027)

Figure 1 is a block diagram explaining a pulse laser device according to one embodiment of this invention.

(0028)

The laser device shown in Figure 1 can be for instance an excimer laser device with a narrow band. The light generated in the narrow band system by narrow band unit 11 is excited and amplified by a charge which is applied from electrodes contained in laser tube 12 and the light is then output to front mirror 13 as oscillated laser light. Detector 15 inputs one part of the output of the laser light from beam splitter 14 and detects its wavelength and pulse energy. Laser controller 16 controls the pulse energy with a controlled laser power source 17 based on command values or set values and based on the detection value of detector 15, enabling to control the pulse energy. In addition, the selection wavelength of narrow band unit 11 is also controlled.

(0029)

On the other hand, a desired input of energy required for the next pulse is applied from light exposure device 3 with pulse energy controller 5 and the pulse energy generated during the next oscillations is forecasted or a command is sent by pulse laser device 11 specifying the pulse energy value. In addition, driver 4 is operated and also the transmittance value of attenuator 2 is controlled according to this forecast value or command value.

(0030)

When an oscillation trigger is input in this manner to pulse laser device 1, pulse laser light will be output form pulse laser device 1, this output light will be attenuated by attenuator 2 to a specified pulse energy level and input to exposure device 3.

(0031)

Figure 2 is a flowchart explaining one embodiment of a pulse generating method used to generate pulse and to forecast the pulse energy value.

(0032)

First, a marker value P is input from exposure device 3 (or processing device) (in step 101). Next, the strength of laser excitation (or the charging voltage of the excitation condenser) V is set (in step 102), In addition, pulse energy Pin forecasted in the internal laser part is calculated (in step 103).

(0033)

Next, transmittance α of attenuator 2 (= P/Pin) is calculated (in step 104). Next, it is determined whether the value α of the calculated transmittance is greater than 1 (in step 105). If it is greater than 1, the operations will proceed with step 106 in which the laser excitation strength will be increased only by specified amount Δ V by performing the operation V =V + Δ V and the operations will be returned again to step 102.

(0034)

On the other hand, if the transmittance value α is less than 1, step 107 will be realized simultaneously with step 108.

The excitation strength V of the laser will be set in step 107 and in step 108, and attenuator 2 will be controlled via driver 4 so as to achieve transmittance α of attenuator 2. Further, a laser oscillation command is issued in step 109 and when the oscillation command is input, the operations will proceed with step 110 resulting in 1 pulse oscillations of pulse laser device 1. When the oscillations are finished, the operations will proceed again with step 101 and the above operations will be repeated.

(0035)

Figure 3 (a) is a flowchart explaining one embodiment of a calculation subroutine used to forecast the pulse energy Pin in the internal part of the laser, while Figure 3 b is a graph indicating the relationship between the pulse energy Pin, pulse number N, and oscillation pause time period T.

(0036)

As shown in Figure 3 (a), first, pulse number N and gas parameter N, obtained from laser oscillation strength (or excitation condenser's charging voltage) V, and the burst start time will be input (in step 1001). In this case, the gas parameters will include the partial pressure, total pressure, gas temperature, etc., for instance of argon gas.

(0037)

Next, the pulse energy Pin calculations will be conducted for forecasting based on these parameters (in step 1002).

(0038)

Figure 3 (b) indicates the pattern of alterations of pulse energy Pin occurring when the oscillation pause time period T is changed with a constant gas parameter G. As shown in the figure, the relationship between the oscillation pause time periods is T3 > T2 > T1. Generally, the longer the oscillation pause time period, the higher the pulse energy achieved when the burst starts.

(0039)

Also, although this is not shown in this figure, when the excitation strength of the laser (or the charging voltage of the excitation condenser) V is increased, this will generate different phenomena occurring during continuous oscillations in the pulse also during the intermediate burst period. In addition, if the partial pressure for instance of Kr gas is increased, the pulse energy Pin will be increased at the start of the burst.

(0040)

When these parameters are stored in memory as a function in the form of a calculating formula or a table, this makes it possible to determine easily with pulse energy controller 5 the pulse energy Pin for respective conditions.

(0041)

Furthermore, if calculation formulas or tables relating to these parameters are prepared for different types of lasers, this makes it possible to calculate with precision the pulse energy Pin in the internal part of the laser also for different types of laser oscillation modes.

(0042)

Figure 4 is a flow chart explaining another embodiment of the pulse oscillation method used to generated a pulse to forecast the pulse energy with pulse energy controller 5.

(0043)

As shown in this flowchart, the difference between this flowchart and the one shown in Figure 2 is that a new step 111 is added in order to store in memory a burst pattern containing the present oscillation conditions after 1 pulse oscillations have been initiated with the pulse laser in step 110. This makes it possible to store in memory the previous burst pattern or the previous cycle, enabling to forecast the present pulse energy according to the trends of the past data.

[page 6]

This thus makes it possible to forecast with an even better precision the pulse energy Pin in the internal part of the laser.

(0044)

Figure 5 (a) is a flowchart explaining an embodiment of the subroutine used for forecasting calculations of the pulse energy in the internal part of the laser, while Figure 5 (b) explains an embodiment of the subroutine used to store in memory the burst pattern for the present conditions.

(0045)

As shown in Figure 5 (a), the initial oscillation pause time period T, laser oscillation strength (or charging voltage of the excitation condenser) V, and pulse number N will be read from the burst starting time (in step 2001). Unlike in the example which is shown in Figure 3 (a), the gas parameter G is omitted as it does not need to be necessarily considered.

(0046)

Next, in step 2002, pulse energy Pinp is read for the internal laser part for pulses generated before the previous cycle under the same or similar conditions corresponding to respective parameters T, V, and N, and Pin = Pinp is established by using for this purpose the forecast value of pulse energy Pin in the internal laser part.

(0047)

On the other hand, as shown in Figure 5 (b), the pulse number N is read in the same manner based on the initial oscillation pause time period T, laser excitation strength (or charging voltage of the excitation condenser) V, and burst starting time (in step 2011). Next, this value is matched with the conditions based on the value of the real output of the pulse energy Pin in the internal laser part and the result is stored in memory (in step 2012).

(0048)

Figure 6 shows a flowchart explaining an embodiment of the pulse generating method used when a marker value P is set for the pulse energy in the internal laser part.

(0049)

In this example, the initial marker pulse energy value P is read (in step 201). Next, transmittance α is set for attenuator 2 and for pulse energy Pin 0 in the internal part of the laser

corresponding to marker pulse energy P (in step 202). Also, step 203 is executed in parallel with step 204. During this step 203, the excitation strength of the laser (or the charging voltage of the excitation condenser) V, etc., is controlled so as to achieve Pin 0 of the pulse energy Pin in the internal laser part. In step 204, the attenuator is controlled to achieve the transmittance α. After this processing is finished, the operations proceed with step 205, the system awaits input of a laser oscillation command and after the laser oscillation command is input, the operations proceed with step 206 and 1 pulse oscillations are generated in pulse laser device 1. When the oscillations are finished, the operations proceed again with step 201 and the above described operations are repeated. Although step 204 was conducted in parallel to step 203 in this example, the invention is not limited in any way by this as both steps can be conducted so that the laser oscillation command is input in advance.

(0050)

Figure 7 explains the subroutine used to determine transmittance α of attenuator 2 and pulse energy Pin 0 in the internal laser part.

(0051)

As shown in Figure 7, first, Pin 0 = Plock is set for marker value Plock of the previous cycle with maker value Pin 0 for pulse energy in the internal laser part (in step 3001), which is followed by calculations of the transmittance α (= P/Pin 0) of the attenuator for light energy value P required for a processing device, etc. (in step 3002) After that, it will be determined whether this attenuator transmittance α established in this manner is greater than 1 (in step 3003). If it is greater than 1, the operations will proceed with step 3004 and the operation Pin 0 = Pin 0 + Δ P will be conducted so that the marking value Pin 0 of the pulse energy in the internal laser part is increased only by a specified amount Δ P and the operations are returned to step 3002.

(0052)

On the other hand, if the transmittance value α determined for the attenuator is not greater than the 1, this routine is finished when the condition $\alpha \leq 1$ is established (in step 3003). This makes it possible to provide response in cases when the pulse energy in the internal laser part is set to a low setting.

(0053)

Next, Embodiment 2 of this invention will be explained based on Figure 8.

(0054)

The difference between the system shown in Figure 8 and the system shown in Figure 1 is that a shutter 8, a pulse energy detection circuit 7, and a beam splitter 6 are deployed in this

system between attenuator 2 and exposure device 3 in order to detect the pulse energy obtained from attenuator 2. Because the output of pulse energy detection circuit 7 is input to pulse energy controller 5, this makes it possible to confirm the transmittance α of attenuator 2 and to provide compensation.

(0055)

Figure 9 is a flowchart explaining the operation of the system of the Embodiment 2 which is shown in Figure 8.

(0056)

The flowchart differs from the flowchart example shown in Figure 6 after step 307. After the laser oscillations are conducted (in step 306), the operations proceed with step 307 and laser output pulse energy Pout and the pulse energy Pin in the internal laser part are read. Next, the operations are continued with step 308. If the value determined for the absolute difference between the set pulse energy P and the laser output pulse energy Pout is in this step smaller than a specified value k, the operations will continue with step 310. If this difference is larger than the specified value k, the operations will proceed with step 309 because this will mean an abnormal event in the external device part.

(0057)

The real transmittance αr will be calculated in step 310 as αr = Pout/, a correction will be applied to correct the ratio of the attenuator based on transmittance αr in step 311 and the operations will be returned again to step 301.

(0058)

Figure 10 shows another example of a flowchart explaining the operation of the system of Embodiment 2 of this example.

(0059)

The difference between this example and the example explained in the flowchart shown in Figure 9 is that a different processing is used after step 401. If the difference established between transmittance α set for attenuator 2 in step 401 and the real transmittance αr (= Pout/Pin) is smaller than a specified value h, the operation is returned as is to step 301.

[page 7]

If this difference is bigger than the specified value h, an abnormal status of attenuator 2 will be determined, a notice will be sent about this abnormal status to an external part (in step

402), a calibrating routine will be applied to the attenuator (in step 403) and the operations will be returned after that to step 301.

(0060)

Figure 11 shows one example of the operation of the subroutine for applied to the attenuator in step 403 as shown in Figure 10.

(0061)

When this subroutine is entered, first, shutter 8 is closed as shown in Figure 8 (in step 4001). Next, laser 1 is oscillated (in step 4002) under conditions including a determined pulse energy Pin in the internal part of the laser or a determined excitation strength of laser 1 (or charging voltage of the excitation condenser) V. Next, the operations proceed with step 4003 in which attenuator 2 is controlled so as to achieve the maximum value of pulse energy Pout output from laser 1. Next, control value dm of attenuator 2 at the time of the maximum Pout in step 4004 and transmittance αm will be stored in memory.

(0062)

Next, a minor change is made in control value d of the attenuator in step 4005 to achieve $d = dm + \Delta$ and the transmittance α (d) is determined for control value d of attenuator 2 in step 4006 and the value is stored in memory. Next, it will be determined in step 4007 whether the minimum transmittance has been reached and if it is not the minimum transmittance, the operations will be returned to step 4005. If it is determined that this is the minimum transmittance, the operations will proceed with step 4008.

(0063)

In step 4008, a compensation will be applied with an approximate formula or table expressing the ratio between control value d of attenuator 2 and transmittance α. After that, shutter 8 is opened and the routine will be finished in step 409. This processing series thus makes it possible to provide compensation with a high degree of precision for the relationship between control value d of attenuator 2 and transmittance α.

(0064)

Figure 12 shows an example of a subroutine used to calculate a correction value based on the real transmittance αr with the operation conducted in step 311 shown in Figure 9.

(0065)

During this routine, first, the present control value d of attenuator 2 and the real

transmittance αe is read (in step 4011). Next, the operations will continue with step 4012 and d0 will be substituted for control value d of attenuator 2 ($d = d0$). In addition, either function F will be calculated to establish $\alpha r = f(d0)$ in step 4013, or a substitution table will be used for function f in step 4014 and the routine is finished.

(0066)

The primary function of function f expressed as $\alpha = kd + b$ can thus be established in this manner and a correction can be achieved with $\alpha = kd - \alpha r - (kd0)$. When a similar correction is applied to each pulse, this makes it possible to regulate energy with a high degree of precision at any time. This correction is very important due to fluctuations and deteriorations of the environment set for the relationship between control value d of attenuator 2 and transmittance α and due to fluctuations of the input energy value, etc.

(0067)

Figure 13 is a flowchart explaining an embodiment of the pulse generating method used for operations generating output of pulse energy by calculating the required pulse energy.

(0068)

First, the required pulse energy P is calculated in step 501 with the subroutine used to calculate P in this step. Next, based on this value P, the marker pulse energy Pin 0 of attenuator 2 and transmittance α are determined (in step 502). Next, step 503 will be run simultaneous with step 504. During step 503, the excitation strength V is controlled so as to achieve marker pulse energy Pin 0 of the pulse energy in the internal laser part. During step 504, attenuator 2 is controlled so as to create transmittance α.

(0069)

Next, it will be determined whether an oscillation command was input for laser 1 (in step 505). When an oscillation command is input, the operations will proceed with step 506 and pulse oscillations of laser 1 will be initiated. Next, the output pulse energy Pout is read and stored in memory (in step 507). The operations will be then returned to step 501.

(0070)

Figure 14 explains a calculating subroutine used to calculate the required pulse energy.

(0071)

During this subroutine, first, the successive integrating exposure value Q, successive integrating pulse number N, and the previous number N from the previous cycle are read as

respective pulse energy values P_{h-N}, P_{h-N+1}, ... P_{h-2}, P_{h-1} (in step 5001). In addition, the required pulse energy is calculated based on these parameter in the next step, step 5002.

(0072)

An explanation of the successive integrating exposure value Q now follows.

(0073)

The successive integrating exposure value Q can be expressed at a given point in time by the sum total of pulse energy P_k during a specified time period. Specifically, it can be calculated as follows:

$$Q = \sum_{k-h-N}^{h-1} P_k$$

(0074)

Assuming that pulse energy P_h is applied at the level of the pulse corresponding to the light energy amount up until now, the desired marker for successive integrating exposure value Q_t will be calculated as:

$$P_h = Q_t - \sum_{k-h-N}^{b-1} P_k$$

In order to achieve a the value of P_h with a desired precision, precise control must be applied per 1 oscillation pulse.

(0075)

In reality, a changing value i will be used for this control as follows:

$$P_h + 1 = Q_t - \sum_{k=h-N+1}^{h} P_k$$
$$P_h + 2 = Q_t - \sum_{k=h-N+2}^{h} P_k$$
....
$$P_h + i = Q_t - \sum_{k=h-N+i}^{b+i-1} P_k$$
$i = 2, 3, 4, 5$ ...

This item will be referred to here as successive integrating exposure value Q.

(0076)

The pulse energy must be calculated with successive integrating calculations because the exposure method is used to calculate the amount of light exposure with the scan method when a

moving (successive) exposure is applied to a mask or a wafer.
[page 8]

The successive integrating pulse number N thus corresponds to the number of the exposure pulses determined in one point on the surface of the wafer.

(0077)

Because as was explained here, the control is applied by calculating the required energy for each pulse, this makes it possible to control the light exposure amount with a high degree of precision even when the scanning method is used to provide output.

(0078)

The explanation above so far did not describe the type of the attenuator 2.

(0079)

As far as the type of the attenuator 2 which can be used in this case is concerned, it is possible to use for this purpose Pockels element, a multilayered dielectric film having a sloping reflectance or a filter consisting of a multilayered film, coated with a multilayered dielectric film characterized by different reflectance amounts due to different incident angles, or an element consisting of a plate which is not coated, a plate provided with a mesh having a specified number of openings, or a plate having a specified absorption coefficient, etc.

(0080)

However, a similar high-speed attenuator which would be capable of varying the transmittance per each pulse by using ultraviolet light rays with a high energy level of an excimer laser basically does not exist. An example of a high-speed attenuator which can be used for similar high-energy ultraviolet light of an excimer laser is either an etalon or an angle dispersion element using a grating and a prism, etc. It is also possible to construct a high-speed attenuator by combining a stress modulator with a light deflecting plate. Synthetic quartz or CaF2, etc., can be also used in a light deflecting plate for high-energy ultraviolet light.

(0081)

Figure 24 explains the construction of an attenuator combining a stress modulator and a deflecting plate according to prior art. As shown in the figure, piezoelectric element 51 is used with substrate 52 for stress modulator and a specified direct current voltage and alternating current waveform are applied via oscillator 54, enabling to change the deflecting direction and to create a large deviation in the resonance of laser 1, which is a narrow band excimer laser. The narrow band excimer laser has a deflecting element built inside the resonator of laser 1,enabling

linear polarization of light beams in the horizontal direction. The output of light from this narrow band excimer laser linearly deflected in the horizontal direction passes through a stress modulator, enabling to change the direction of polarized light. Accordingly, when the laser light is output from the laser modulator passes through a deflecting plate, the laser light will be attenuated and after that it will be input to exposure device 3.

(0082)

The attenuator thus makes it possible to vary the transmittance by changing the size of the direct current waveform and the direction current voltage applied in this manner.

(0083)

Figure 15 is a graph explaining the principle of the construction of an attenuator using a wavelength selection element.

(0084)

As shown in Figure 15 (a), the maximum transmittance value is achieved when the central wavelength of the selection spectrum of the wavelength selection element is coincidental with the laser oscillation wavelength. The transmittance can be changed to about 80% of the transmittance obtained as shown in Figure 15 (a) when the selection wavelength (central wavelength) of the wavelength selection element is slightly shifted from the oscillation wavelength of the laser as shown in Figure 15 (b). In addition, the transmittance can be shifted so that it is reduced to about 50% as shown in Figure 15 (c). This makes it possible to vary the transmittance by varying the selection wavelength of an attenuator by using in this manner a wavelength selection element.

(0085)

Figure 16 explains a construction example of a wavelength selection element which uses a transmitting diffraction element, a reflecting diffraction element and a prism.

(0086)

As shown in Figure 16 (a), the primary light which has passed through transmitting diffraction element 20 is selected by slit 21 and then output.

(0087)

As shown in figure 16 (b), the light diffracted by reflecting diffraction element 22 is selected and output by slit 23.

(0088)

As indicated in figure 16 (c) which shows an example utilizing dispersion of the diffraction ratio of prism 24, the light passing through prism 24 is selected and output by slit 25.

(0089)

This makes it possible to realize modifications of the angle which is set for the prism or for the diffraction grating with the selection wavelength in this example. In addition, a piezo element can be used to change the angle with a high speed.

(0090)

Figure 17 shows an example using an etalon for the wave selection element.

(0091)

As shown in Figure 17 (a), 2 substrate layers of a divided piezo element (PZT) 30 are used with a laminated shape of an element coated with a reflecting film (multilayered dielectric film 31 when ultraviolet rays are used). When a high voltage is applied via driver 32 to piezo element (PZT) 30, the gap interval of substrate reflecting films 31 is changed, making it possible to shift the selection wavelength.

(0092)

When the piezo electric element (PZT) 30 of this example is used as a spacer of an etalon, it can be deployed opposite a holder of each substrate reflecting film, enabling an optimal deployment of the piezo element between the reflecting film and the holder.

(0093)

Since in this case it is possible to modify the system by changing the gap interval of the etalon at a very high speed simply by controlling the voltage applied to the piezo element (PZT), the transmittance can thus be changed in this manner easily by simply changing the angle of the etalon while using pulse meter 33.

(0094)

Figure 17 (b) shows an example in which the etalon which has a fixed gap interval is provided with a holder 35 mounted so as to make it possible to control the angle of the etalon. This makes it possible to change the transmittance by changing the angle of the etalon while using for this purpose pulse meter 33.

(0095)

Figure 17 (c) shows an example of and etalon chamber deployment wherein a window is added to an etalon provided with a fixed gap interval. The transmittance can thus be changed by controlling the air pressure inside the chamber air gap with a pressure regulator 41, etc.

(0096)

Figure 17 (d) shows an example enabling to change the transmittance by shifting the selection wavelength when the gap interval is varied by pressing down pusher 34 on the substrate of the etalon, while a holder 36 is deployed in an etalon which has a fixed gap interval.

[page 9]

This can be realized by using a piezo element (PZT) or a liner actuator for pusher 34.

(0097)

Generally, the wavelength can be selected with this etalon design with a repeated reflection interference. The operation is explained in the enclosed Figure 18. As shown in the figure, Ai is the incident light entering the internal part of the etalon with substrate G2, Bi is light reflected inside the etalon with G1, Ti is the light output in the forward direction of incident light from the etalon, and Ri is the light reflected in the backward direction of incident light from the etalon. The operation can be thus expressed by basic formula (1).

(0098)

$$m\lambda = 2\ nd \cos\theta \qquad (1)$$

In this formula, m is the degree (order), λ is the wavelength, n is the index of refraction in the gap, d is the mirror interval, and θ is the angle of incident light rays coming into the etalon.

(0099)

Formula (2) explains the integrating calculation used to obtain unlimited transmitted light as shown in Figure 18.

(0100)

$$I\ (Q) = [1 + \{2f/\pi)\ \sin\ (\varepsilon/2)\ \{^{2}\}^{-1} \qquad (2)$$

According to this formula, $f = \pi\sqrt{R}/\ (1\text{-}R)$, $\varepsilon = 2\ k d\cos\theta$, $k = 2\ \pi/\lambda$, f is finesse, and R is

the reflectance of the mirror.

(0101)

Figure 19 indicates the strength of transmitted light obtained with a repeated reflection interference determined according to Formula (2).

(0102)

When the reflectance R is increased, the minimum value of transmittance I (Q) will be decreased. In addition, when ε is set to an integral multiplier, transmittance I (Q) will be 1 when the central wavelength is created. The difference between this selection wavelength and another selection wavelength is called free spectral range (FSR).

(0103)

Next, examples of the transmittance achieved when an attenuator is used with an etalon will be explained on the table provided in Figure 27. As indicated in the table shown in Figure 27, the table shows the results of calculations of the adjusting range for pulse energy (%) and of the minimum transmittance (%) when the reflectance R of the etalon is changed as shown in the table.

(0104)

Based on the results of the calculations shown in this table, a sufficiently wide adjustment of the pulse energy can be achieved if the reflectance R of the mirror is 39%. Generally, the mirror reflectance R must be at least 90% in order to increase the finesse f when measuring a spectrum while using a narrow band system with a laser spectrum using an etalon. When the reflectance R of the etalon mirror is increased, even if the absorbance of the reflecting film is small (the film absorption cannot be ignored when ultraviolet rays are used), the transmittance will be greatly reduced and it will not reach 100% with the selection wave because the number of repeated reflections will be greatly increased.

(0105)

Figure 20 explains the relationship between reflectance R and transmittance I (Q) when an attenuator of a KrF excimer laser is used with an etalon.

(0107)

The maximum etalon transmittance Tmax can be expressed by Formula 3.

(0107)

$$Tmax = \{1 - A/ (A / (1 - R) \}^{2} \qquad (3)$$

(0108)

Figure 20 is a graph indicating the status when the absorbance A of a reflecting film is 2 and 3%. As one can see from the figure, the maximum absorbance will be about 50% with a reflectance of at least 90%. Conversely, if the reflectance is less than 39%, the maximum assimilatory quotient of at least 90% will be reached and a very small loss will be created.

(0109)

Since the spectral shape of the etalon is not a problem when an attenuator is used, a reflectance R of no more than 39% is sufficient.

(0110)

When the reflectance R is increased, the number of repeated reflection will be also increased due to increased absorption in the film, a larger drift of the selection wavelength will be created by a higher temperature, lowering the resistance of the film and shortening its life span. A film which has a reflectance R of less than 39% has a small absorption and the selection wave will have hardly any drift at all. In addition, the resistance of the etalon is also increased and the life span is dramatically increased.

(0111)

Further, the variation amount of the etalon gap required for transition from the maximum to the minimum etalon transmittance is expressed as $\lambda/4$. If the wavelength is for example λ = 248 nm, the variation amount required from the maximum transmittance to the minimum transmittance is 62 nm. A piezo element for use with such a small variation amount can be easily realized, the response characteristics of the pieze element corresponding to several tens of nm/μm will be sufficient, and a sufficient response can be provided in an excimer laser attenuator using a repeating frequency of several kHz when the gap interval is changed at a high speed.

(0112)

Figure 21 shows an example of a subroutine used to control an attenuator so as to achieve transmittance α while using a piezo element to modify the gap interval with an attenuator used in an etalon.

(0013)

First, the displacement amount Δd of the realized piezo element is calculated from the initial transmittance α (in step 6001). Next, the voltage Vp (= β Δd) to be applied to the piezo

element is calculated from this displacement amount Δd (in step 6002). Next, the operations will continue with step 6003 in which the applied voltage data Vp is sent to the driver of the piezo element and the voltage application is finished.

(0114)

Figure 22 explains a construction diagram of a design detecting the standard light when incident light enters an attenuator as standard light. Because the light can be detected as shown in the figure after the standard light has passed through the attenuator as incident light, this makes it possible to control the pulse energy with a very high precision since the transmittance of the attenuator can be calibrated at any time.

(0115)

Figure 23 (a) is a flowchart example explaining detection of transmittance of the standard light in an attenuator.

[page 10]

(1116)

As shown in the flowchart, first, the standard light passing through the attenuator will be detected (in step 7001). Next, correction value dc will be calculated as an attenuator correction value based on the detected value of the standard light (in step 7002) and the operation is finished.

(0117)

This chart can be also used for instance with the steps mentioned in Figure 2 above from step 108, or other steps can be also conducted in parallel.

(0118)

In a concrete example it is possible to use for instance light emitted with 253.7 nm from a low-pressure mercury lamp having a wavelength in the vicinity of 248 nm for KrF excimer laser wavelength of standard light. A standard light detector can be used to detect the optical strength of the standard light of the passing through the system, as well as its position, interference stripes, etc. The standard light will not be hindered by laser light or the light rays emitted from the lamp as long as the wavelength is stable.

(0119)

Figure 23 (b) shows a flowchart example explaining the operation used to control an

attenuator so as to achieve transmittance α when standard light is used.

(0120)

First, the control value d is calculated from the initial transmittance α (in step 7011). Next, the control value is substituted (d = d + dc) (in step 7012). Next, the operations will continue with step 7013 in which the attenuator control value d is output to the driver and the operation is finished.

(0121)

Figure 24 explains a construction diagram applicable to this case using a stress modulator with a coated piezo element on a substrate wherein a specified direct current voltage and frequency oscillation output is applied, making it possible to create a large deviation and change the deflection direction by the induced resonance. For example when a deflecting element is built into a laser resonator of a narrow band excimer laser, direct light rays can be deflected in the horizontal direction. The light output from the narrow band excimer laser can be changed to polarized light when the light passes through a stress modulator. The light output from the stress modulator which changed the polarization direction will be attenuated when it passes through a deflection plate and after that it will be input to an exposure device. When an attenuator is used in this manner with a stress modulator, this makes it possible to change the transmittance at a high speed by changing the applied voltage.

(0122)

(Effect of the Invention)

1

Because the pulse energy to be output next from the laser is calculated, the transmittance of a variable attenuation means can be controlled for each pulse to achieve a set pulse energy of the output pulse energy. This makes it possible to control the pulse energy at a high speed and with an optimal precision.

(0123)

2

The integrating value of the laser pulse controls the variable attenuation means per each pulse in order to achieve a constant pulse energy with a set value of the pulse energy for individual pulse energy levels.

(0124)

3

The transmittance of the attenuator is monitored at all times. Because of that, a generated drift can be controlled with a variable attenuation means and the pulse energy can be controlled with a high precision for a long time period. In addition, an abnormal status of the variable attenuation means can be also detected by a comparison of the set transmittance to the real transmittance.

(0125)

4

A wavelength selection element is used as a variable attenuation means, enabling optical attenuation by changing the selection wavelength. Because of that, the transmittance of the variable attenuation means can be easily changed for each pulse energy level. Also, when an etalon is used as a wavelength selection element, the transmittance can be changed at a very high speed by driving operations applied to a piezo element with a gap interval between the mirrors of the etalon.

(0126)

5

Because the transmittance of incident light in the standard light of the attenuator is detected, this makes it possible to correct the pulse energy with a very high degree of precision even when there are no laser oscillations.

(0127)

As was explained above, because the device of this invention makes it possible to control with a high precision and at a high speed the pulse energy of a pulse laser device, an optimal device is realized in the form of a pulse energy controlling device, required to ensure a high depth precision of a processing device and an exposure device using the scan exposure method.

(Brief Explanation of Figures)

(Figure 1)

Figure 1 is a construction diagram explaining the construction of a pulse energy control device according to one embodiment of this invention.

(Figure 2)

Figure 2 shows a flowchart example explaining the operation of the embodiment shown

in Figure 1.
(Figure 3)

A diagram explaining the influence of the oscillation pause time period with a flowchart explaining the calculation of the pulse energy for the pulse constant.

(Figure 4)

Another flowchart example explaining the generation of light pulses and forecasting of the pulse energy according to the embodiment shown in Figure 1.

(Figure 5)

A flowchart explaining how the pulse energy conditions are stored in memory and another flowchart explaining forecasting of the pulse energy in the internal part of the laser.

(Figure 6)

A flowchart explaining the light pulse generation when a marker value is set for the pulse energy.

(Figure 7)

A flowchart explaining how the pulse energy in the internal part of the laser and the transmittance of the attenuator are determined.

(Figure 8)

A construction diagram explaining a pulse energy control device according to another embodiment of this invention.

(Figure 9)

A flowchart example explaining the operation of the embodiment shown in Figure 2.

(Figure 10)

Another flowchart example explaining the operation of the embodiment shown in Figure 2.

(Figure 11)

A flowchart explaining the calibrating routine used for the attenuator.

(Figure 12)

A flowchart of the correcting routine for transmittance.

(Figure 13)

A flowchart of the output of pulses of pulse energy used to calculate the pulse energy.

(Figure 14)

A flowchart explaining the calculation routine used to calculate the required pulse energy.

(Figure 15)

A diagram explaining the principle of an attenuator using a wavelength selection element.

[page 11]

(Figure 16)

A construction diagram of an attenuator using a wavelength selection element.

(Figure 17)

A construction diagram of an attenuator using an etalon as a wavelength selection element.

(Figure 18)

A diagram explaining the wavelength selection operation with an etalon.

((Figure 19)

A graph explaining the transmitting strength with a repeated reflection interference.

(Figure 20)

A graph explaining the maximum transmittance when the absorbance of a reflecting film is 2% and 3%.

(Figure 21)

A flowchart explaining a subroutine used to control the transmittance with an attenuator using an etalon.

(Figure 22)

A construction diagram of one embodiment of this invention wherein the transmittance is calibrated when incident light passes through an attenuator as standard light.

(Figure 23)

A flowchart explaining calibration of attenuator transmittance by using standard light.

(Figure 24)

A construction diagram of an attenuator construction according to prior combining a deflecting plate with a stress modulator.

(Figure 25)

A construction diagram of a pulse energy control device according to prior art.

(Figure 26)

A diagram explaining the pulse generation status of a pulse laser device.

(Figure 27)

A table showing the regulating range of pulse energy and the minimum transmittance when the etalon reflectance is changed.

(Explanation of Symbols)

1	pulse laser device
2	attenuator
3	exposure device
4	driver
5	pulse energy controller
6	beam splitter
7	pulse energy detection device
8	shutter

(Figure 1)

2 attenuator
3 exposure device
4 driver
5 pulse energy controller
11 narrow band unit
12 laser tube
14 detector
16 laser controller - pulse laser
17 power source

(Figure 8)

2 attenuator
3 exposure device
4 driver
5 pulse energy controller
11 narrow band unit
12 laser tube
14 detector
16 laser controller - pulse laser
17 power source

(Figure 18)

[page 12]

(Figure 2)

100 start
101 read only target pulse energy P
102 set laser excitation strength V
103 calculate forecast pulse energy Pin in the internal laser part
107 set laser excitation strength to V
108 control attenuator so as to achieve transmittance α
109 was a laser oscillation command input?
110 oscillation

(Figure 5)

(a)

start

2001 read number of pulses N from the initial burst, laser excitation strength V, and oscillation pause time period T

2002 read pulse energy Pin in the internal part output previously or the previous conditions identical to the present conditions T, V, and N

2003 return

(Figure 5)

(b)

start

2011 read number of pulses N from the initial burs, laser excitation strength V, and oscillation pause time period T

2012 store in memory oscillation conditions and pulse energy Pin output in the internal part of the laser

return

(Figure 26)

[vertical axis] pulse energy

[from left to right] oscillation pause oscillation pause pause time period

[horizontal axis] time t

[page 13]

(Figure 3)

(a)

start

1001 read number of pulses N and gas parameter G from the initial burst, laser excitation strength V and oscillation pause time period T

1002 calculate pulse energy Pin forecasted from T, V, N, and G

return

(Figure 3)

(b)

[vertical axis] pulse energy
[horizontal axis] number of pulses

(Figure 4)

100 start

101 read target pulse energy P

102 set laser oscillation strength V

103 calculate pulse energy Pin forecast in the internal laser part

107 set laser excitation strength V

108 control attenuator so as to achieve transmittance α

109 was a laser oscillation command input?

110 oscillation

111 store in memory the burst pattern (oscillation conditions) during present oscillations

(Figure 19)

[page 14]

(Figure 6)

200 start

201 read target pulse energy P

202 determine transmittance α of the attenuator and target energy Pin in the internal laser part

203 control excitation strength V so as to create energy Pin 0 in the internal laser part

204 control the attenuator so as to achieve transmittance α

205 was an oscillation command input to the laser?

206 oscillations

(Figure 20)

[horizontal axis] reflectance

(Figure 11)

start

4001 close the shutter

4002 laser oscillates under specified conditions

4003 control attenuator to achieve maximum pulse energy Pout of the output laser

4004 store in memory transmittance α and control value dm of the attenuator during Pout

4005 change the control value d of the attenuator $d = dm + \Delta d$

4006 store in memory transmittance α (d) corresponding to control value d

4007 was the minimum transmittance α created?

4008 rewrite the relationship table containing transmittance α and control value d of the attenuator

4009 open the shutter

return

[page 15]

(Figure 7)

start

3001 set the internal target energy Pin to a set value or to the pulse energy value Plock (power lock value) to the previous cycle target value Pin0 = Plock

return

(Figure 12)

start

4011 read the real transmittance α_r and the control value d of the attenuator

4013 calculate function f to establish the relationship $\alpha_r = f\,(d0)$

4014 rewrite the table expressing function f

return

(Figure 14)

start

5001 read pulse energy P_{h-N+1}, P_{h-N+2}, ... P_h from the previous cycle to number N-1, the median number of successive pulses N, and the successive integrating light exposure value Q

5002 calculated the required pulse energy P
[see formula]

return

[page 16]

(Figure 9)

300 start

301 read target pulse energy P

302 set transmittance value α of the attenuator and target energy Pin 0 in the internal laser part

303 control excitation strength V to achieve energy Pin 0 in the internal the laser part

304 control attenuator to create transmittance α

305 was a laser oscillation command input?

307 read output pulse energy Pout and pulse energy Pin in the internal laser part

309 send a notice about an abnormal status to an external part

[page 17]

(Figure 10)

300 start

301 read the target pulse energy P

302 set the transmittance α of the attenuator and the target energy Pin0 in the internal laser part

303 control excitation strength V to achieve energy Pin0 in the internal laser part

304 control attenuator to achieve transmittance α

305 was an oscillation command input to the laser?

306 oscillations

307 read the output pulse energy Pout and the pulse energy Pin in the internal laser part

309 send notice about an abnormal status to an external part

402 abnormal attenuator status detected

403 attenuator calibration routine

[page 18]

(Figure 13)

start

501 subroutine for calculation of required pulse energy P

502 subroutine setting transmittance α of the attenuator and target energy Pin0 in the internal laser part

503 control excitation strength so as to achieve energy Pin0 in the internal laser part

504 control attenuator to achieve transmittance α

505 was an oscillation command input to the laser?

506 oscillations

507 store in memory read value of the output pulse energy Pout

(Figure 15)

(a)
[vertical axis] transmittance
[horizontal axis] wavelength
[upper horizontal axis item] selection spectrum of the wavelength selection element
[lower horizontal axis item] laser light spectrum

(b)
[vertical axis] transmittance
[horizontal axis] wavelength
[horizontal axis item] → wavelength shift

(c)
[horizontal axis] transmittance
[vertical axis item] → wavelength

(Figure 27)

Mirror Reflectance (%)	Minimum Reflectance (%)	Pulse Energy Adjustment Range (%)
4 (no coating)	88.2	± 7
6	78.6	± 10
13	59.3	± 20
23	39.2	± 30
39	19.2	± 40

[page 19]

(Figure 16)

20 transmittance diffraction grating
A 0 light
B primary light
C angle modification
D direction of movement
E angle modification
F angle modification
21 slit
22 reflecting diffraction grating
23 to slit ↔ direction of movement
24 diffusion prism
25 slit

(Figure 17)

(a)
31 reflecting film

(b)
32 driver
33 pulse motor
34 pusher
35 holder
36 spacer
37 hinge

(c)

40	window
41	pressure adjusting device
G	← inert gas
32	driver

(d)

32	driver
34	pusher

(Figure 22)

2	attenuator
3	exposure device
4	driver
5	pulse energy controller
6	beam splitter
7	pulse energy detector
8	shutter
9	source of standard light
11	narrow band unit
12	laser tube
14	detector
16	laser controller
17	power source
H	pulse laser

[page 20]

(Figure 21)

start

6001 displacement amount Δd of the piezoelectric element from transmittance α

6002 calculate voltage Vp applied to the piezoelectric $\Delta p = \beta\Delta d$

6003 apply voltage to send applied voltage Vp data to th driver of the piezoelectric element

return

(Figure 23)

(a)

start

7001 detect the standard light passing through the attenuator

7002 calculate correction value dc based on the detected value of the standard light

return

(b)

start

7001 calculate control value d from transmittance α

7012 convert the correction value by adding correction value dc to control value d
$d = d + dc$

7013 output the control value d of the attenuator to the driver

return

[page 21]

(Figure 24)

3	exposure device
5	pulse energy controller
11	narrow band unit
12	laser tube
15	detector
16	laser controller
17	pulse laser
51	piezo element
53	deflecting plate
54	oscillator

(Figure 25)

(a)

91	pulse system light source
92	variable attenuator
93	light value monitor
94	exposure performing apparatus
95	controller

(b)

91	pulse system light source
94	exposure performing apparatus
95	controller

(Procedural Amendment)	
(Filed on)	August 23, 1995
(Procedural Amendment 1)	
(Name of the Amended Document)	Specifications
(Amended Item)	Brief Explanation of Figures
(Method of Amendment)	Change
(Content of Amendment)	
(Brief Explanation of Figures)	

(Figure 1)

A construction diagram explaining a pulse energy controlling device according to one

embodiment of this invention.

(Figure 2)

One example of an operation flowchart of the embodiment shown in Figure 1.

(Figure 3)

A diagram showing the influence of the oscillation time period and a flowchart explaining the calculation of the pulse energy from a pulse constant.

(Figure 4)

Another flowchart example explaining generation of light pulses with forecasting of pulse energy in the embodiment shown in Figure 1.

[page 22]

(Figure 5)

A flowchart explaining how pulse conditions are stored in memory, as well as a flowchart explaining forecasting of pulse energy in the internal of the laser.

(Figure 6)

A flowchart explaining generation of light pulses when a target value is set for the pulse energy.

(Figure 7)

A flowchart explaining determination of the transmittance of an attenuator and of the pulse energy in the internal laser part.

(Figure 8)

A configuration diagram of a pulse energy controlling device according to another embodiment of this invention.

(Figure 9)

One example of an operation flowchart of the embodiment shown in Figure 2.

(Figure 10)

Another example of an operation flowchart of the embodiment shown in Figure 2.

(Figure 11)

A flowchart explaining an attenuator calibrating routine.

(Figure 12)

A flowchart explaining a transmittance calibrating routine.

(Figure 13)

A flowchart explaining output of pulses of pulse energy with a calculation of the pulse energy.

(Figure 14)

A flowchart explaining a calculating routine used to calculate required pulse energy.

(Figure 15)

A diagram explaining the principle of an attenuator with a wavelength selection element.

(Figure 16)

A configuration diagram of an attenuator with a wavelength selection element.

(Figure 17)

A configuration diagram of an attenuator using an etalon as a wavelength selection element.

(Figure 18)

A diagram explaining the wavelength selection operation with an etalon.

(Figure 19)

A graph of the transmitting strength with a repeated reflection interference.

(Figure 20)

A graph showing a maximum transmittance when the absorbance of a reflecting film is

2% and 3%.

(Figure 21)

A flowchart of a subroutine used to control transmittance by using an etalon for an attenuator.

(Figure 22)

A configuration diagram of one embodiment of this invention in which the transmittance is calibrated with incident transmitted light containing standard light in an attenuator.

(Figure 23)

A flowchart explaining calibration of attenuator transmittance by using standard light.

(Figure 24)

A configuration diagram of an attenuator combining according to prior art a stress modulator with a light deflecting plate.

(Figure 25)

A configuration diagram of a pulse energy controlling device according to prior art.

(Figure 26)

A diagram explaining the pulse generation status of a pulse laser device.

(Figure 27)

A table showing the adjustment range of pulse energy and the minimum transmittance when etalon reflectance is changed.

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